Report Date: March 1, 2002

Semi-Annual Technical Progress Report

PREFERRED WATERFLOOD MANAGEMENT PRACTICES FOR THE SPRABERRY TREND AREA

DOE Contract No.: DE-FC26-01BC15274

Harold Vance Department of Petroleum Engineering
Texas A& M University
3116 TAMU
College Station, TX 77843-3116
(979) 845-2241

Contract Date:	September 1, 2001
Anticipated Completion Date:	September 1, 2003
Program Manager:	Bill Knight Pioneer Natural Resources
Principal Investigator:	David S. Schechter Harold Vance Department of Petroleum Engineering
Contracting Officer's Representative:	Dan Ferguson National Petroleum Technology Office
Report Period:	Sept 1, 2001- Feb 28, 2002

DISCLAIMER

TABLE OF CONTENTS

LIST OF TABLES

-

LIST OF FIGURES

Objective

The objective of this project is to significantly increase field-wide production in the Spraberry Trend in a short time frame by application of preferred practices for managing and optimizing water injection. A secondary and synergistic objective is purification and injection of produced water into Spraberry reservoirs.

Review of Upper and Lower Pilots in the Spraberry Area

Up to now, most of the oil production in the Spraberry area has been recovered from the Upper Spraberry. Several pilots have been attempted to establish the production from the Lower Spraberry. The objective of this study, thus, to review several waterflood pilots which can be used to justify the reason of poor performance of Lower Spraberry and to propose a method to place the injection and production wells to increase the oil recovery from Spraberry area. A number of papers have been published concerning the performance in the Lower Spraberry during the waterflooding as presented follows.

In 1963 Elkins and Skov[1] compared the water injection into Lower and Upper Spraberry in the Driver Unit. They found that the water injection into Lower Spraberry was lesser than Upper Spraberry because Lower Spraberry had one third-less injection wells, lower intake capacity and less volume of water injection.
No significant effect of injection had been noted in any lower Spraberry producing wells after injecting about 1,000 bbl per acre. They suggested at least 2,000 bbl per acre water injection required to fill up the Lower Spraberry. The water injection volume required to fill up the Upper Spraberry is less, only 900 bbl per acre because Upper Spraberry has lower saturation pressure and lower formation factor compared to Lower Spraberry has.
Even though the properties of the matrix and the present of vertical fractures in the Lower sand are similar to those of the Upper sand but they doubted the oil recovery per acre would be the same due to the greater oil shrinkage and less fracture intensity.

Again in 1968, Elkins *et al*[2] analyzed the effectiveness of water injection into Lower Spraberry in the Area 1 of Driver Unit. The water was injected separately into the Upper and Lower Spraberry. First water injection began on March 31, 1961. Through June 1968 about 1,640 bbl/acre of water had been injected into the Lower Spraberry. Some of the water injection had been lost through leaks to the Upper Spraberry. Production performances before and after water injection indicate no significant water breakthrough had occurred in any producing wells from Lower Spraberry. The low injection capacities of about 200 to 1,000 b/d with 300 to 400 psi surface pressure in Lower Spraberry compared to 10,000 to 15,000 b/d on vacuum or at moderate surface pressure in Upper Spraberry suggested that continuity and intensity of natural fractures is less in the Lower Spraberry than in the Upper.

In the same year, Guidroz[3] reviewed the performance of the water injection in Lower Spraberry of the Preston Unit. In this Unit the water was injected at the Upper and Lower Spraberry simultaneously with approximately constant injection rate of 1000 bpd per injection well. The water injection was started in February 1965. It was divided equally

between the Upper and Lower zones from start of injection to June 1968. Almost all injection wells were dually completed so as to permit independent injection into the Upper and Lower Spraberry zones. Injection into the lower zone was through tubing and into the upper zone was down tubing-casing annulus. Even though no significant problems had been encountered in obtaining desired injection rates but the corrosion problem exited particularly in the tubing-casing annulus. The corrosion problem caused at least six injection wells where the tubing and tubing-casing annulus were in communication with one another. Cumulative water injected to August 1, 1968 was 614 bbl/acre into the upper zone and 477 bbl/acre into the lower zone. Again, there was no positive indication that the lower zone was responding to injection. Only upper zone had responded to injection and had produced 80 % of the production capacity. Due to poor response of Lower Sprabery coupled with a corrosion problem in the injection well, He proposed to discontinue injection into and production from Lower Spraberry by recompleting all injection wells as single Upper Spraberry wells and isolating the Lower zone in all production wells.

In other pilot area, E.T O'Daniel Pilot Area, three wells, i.e. wells17, 18 and 21 were attempted to establish Lower Spraberry production in that area. The results showed that the Lower Spraberry was non-commercial. Well 17 had been P&A and well 21 was recompleted as an Upper Spraberry producer. Well 18 was plugged back to the Upper Spraberry and was converted to an injector in 1961.

The positive response of water injection in Lower Spraberry was observed in the JoMill (Spraberry) Field.[5] The JoMill Field was discovered in February 1954 and unitized by Texaco in February 1, 1969. The Unit was originally developed on 80-acre proration units, with 40-acre development beginning in 1978. The waterflood pilot was initiated in September 1969 and consisted of 13 injection wells forming peripheral injection pattern. Following the improved production performance under the pilot, the peripheral water injection was expanded to the entire unit with conversion of another 31 injection wells in 1973. Starting in 1986, a total of 55 production wells were converted to injection to establish a line drive injection pattern. In 1996 the unit had 173 producers and 92 injectors. The production had steadily increased from average 2000 bpd before pilot waterflood to about 6000 bpd in 1996. In 1996 the first horizontal injection well (well 1425H) was drilled between two rows of producers. A significant response of oil production was observed. The oil production rate from offsets wells increased from average 100 bpd in May 97 to average 425 bpd in Nov 98.

This paper reviews the waterflooding performance in the four recent waterflood pilots. Three pilots were performed in the Midkiff Unit and the other one was conducted in the E.T O'Daniel Pilot. Three recent water injection pilots were attempt in the Midkiff Unit to establish the Upper and Lower Spraberry production. They are "Lower-McDonald" pilot, "Upper-McDonald" pilot and "Upper and Lower-Heckman" pilot. We have divided the wells as on-trend and off-trend wells to investigate the effect of placing the injection and production wells to the oil production rate.
The "Lower-McDonald" was started in 18 July 1993 and continued until now.An average of 500 bwpd/well was injected through four injectors. About 600,000 bbls of water was

injected on 80-acre pilot in a five spot pattern. The location of the wells is shown in Fig. 1. The wells are grouped into on-trend and off-trend wells following the fracture orientation obtained from core analysis. The "star" symbol indicates the off-trend well and "circle" symbol indicates the on-trend well. Six wells were taken as off-trend wells and eight wells were taken as on-trend wells. The off-trend and on-trend production responses are shown in Figs. 2 and 3. To differentiate the cause of production response either from waterflood or adding more wells, the number of wells is plotted in the same graph. The off-trend and on-trend production wells show no response to waterflood. The positive response was only due to adding more wells. We are, thus, unable to quantify additional oil recovery from wells that completed in the Lower zone.

Other McDonald pilot was started in 4 July 1993 and completed only in the Upper zone. The location of the pilot and wells is shown Fig. 4. Six wells were taken as off-trend wells and 15 wells were taken as on-trend wells. A total of 1,405,695 bbls of water with average 500 bwpd was injected during the water injection course. The off-trend and on-trend responses are shown in Figs. 5 and 6. No waterflood response was observed in the off-trend wells whereas a significant waterflood response was noted in the on-trend wells. Even though one well was added during the water injection but the production response was obviously from waterflood response alone. A decline curve was made to delineate the incremental oil recovery. The incremental oil recovery from Upper Spraberry in the "Upper-McDonald" pilot after waterflood baseline is shown in Fig. 7.

The third waterflood pilot reviewed in this study is "Heckman" pilot. The injection wells were completed in the Upper and Lower zones. The 80-acre pilot location is located in the Tr36 of Midkiff Unit as shown in Fig. 8. The water injection was started in 1996. The number of wells grouped as on-trend and off-trend wells are 18 wells and nine wells, respectively. Both on-trend and off-trend wells show response to waterflood as shown in Figs. 9 and 10. After initiation of water injection, immediate increase in oil production was noted in the on-trend wells whereas the response in off-trend wells was delayed as expected. Higher production response is obtained in the on-trend wells than in the off-trend wells. The incremental gain of oil recovery after waterflood base line is about 5 – 8 bbls for each of on-trend wells that responded and about 0-5 bbls for each of off-trend wells as shown Fig. 11.

The last pilot is the E.T O'Daniel Pilot as part of DOE project. Additional information of this project can be found in our annual reports.[6] The water injection started in October 1999. We have divided oil production into 23 off-trend and 7 on-trend wells and the results are shown in Fig. 12. Incremental oil production has steadily increased in on-trend wells to a current level near 150 bopd (Fig. 13). This represents an incremental gain of 20 – 25 barrels for each of the seven wells that responded.

Conclusion

1. Based on the comparison performance with Upper Spraberry, the probability reason of poor performance of lower Spraberry can be summarized as follows:

- Low water intake capacity indicates probability of lesser extend of fracture system.
- Low volume of water injection (bbl/per acre).
- High oil shrinkage factor.

2. The result from four waterflood pilots indicates that the on-trend wells respond favorably compared to the off-trend wells. Thus, placing production and injection wells along the same fracture orientation may increase oil recovery in the Spraberry area.

References

1. Elkins, L.F and Skov, A. M.: "Cyclic Water Flooding the Spraberry Utilizes "End Effect" to Increase Oil Production Rate," ***JPT*** (Aug., 1963), 877.
2. Elkins, L.F., Skov, A. M., and Gould, R.C.: "Progress Report on Spraberry Waterflood Reservoir Performance, Well Stimulation and Water Treating and Handling" *Trans.,* AIME (1968) **243**.
3. Guidroz, G.M.: Proposal to Discontinue Injection into and Production from Lower Spraberry, Preston Spraberry Unit. Mobil Oil Corporation, Interim report (Oct., 1968)
4. Carr, L.A. and Thiebaud, R.L.: "E.T. O'Daniel Performance Review, Spraberry Trend Area Field, Midland County, Texas," Interoffice Correspondence (Jan 15, 1979).
5. Texaco Exploration and Production Inc.: "Modern Reservoir Management: Improved Recovery in The JoMill (Spraberry) Field, West Texas" U.S. DOE Proposal No. DE-PS26-99BC15144 (May 1999).
6. Schechter, D.S.: "Advanced Reservoir Characterization and Evaluation of CO_2 Gravity Drainage in the Naturally Fractured Spraberry Trend Area," Six Annual Technical Progress Report, U.S. DOE Contract No. DE-FC22-95BC14942 (Oct 2001).

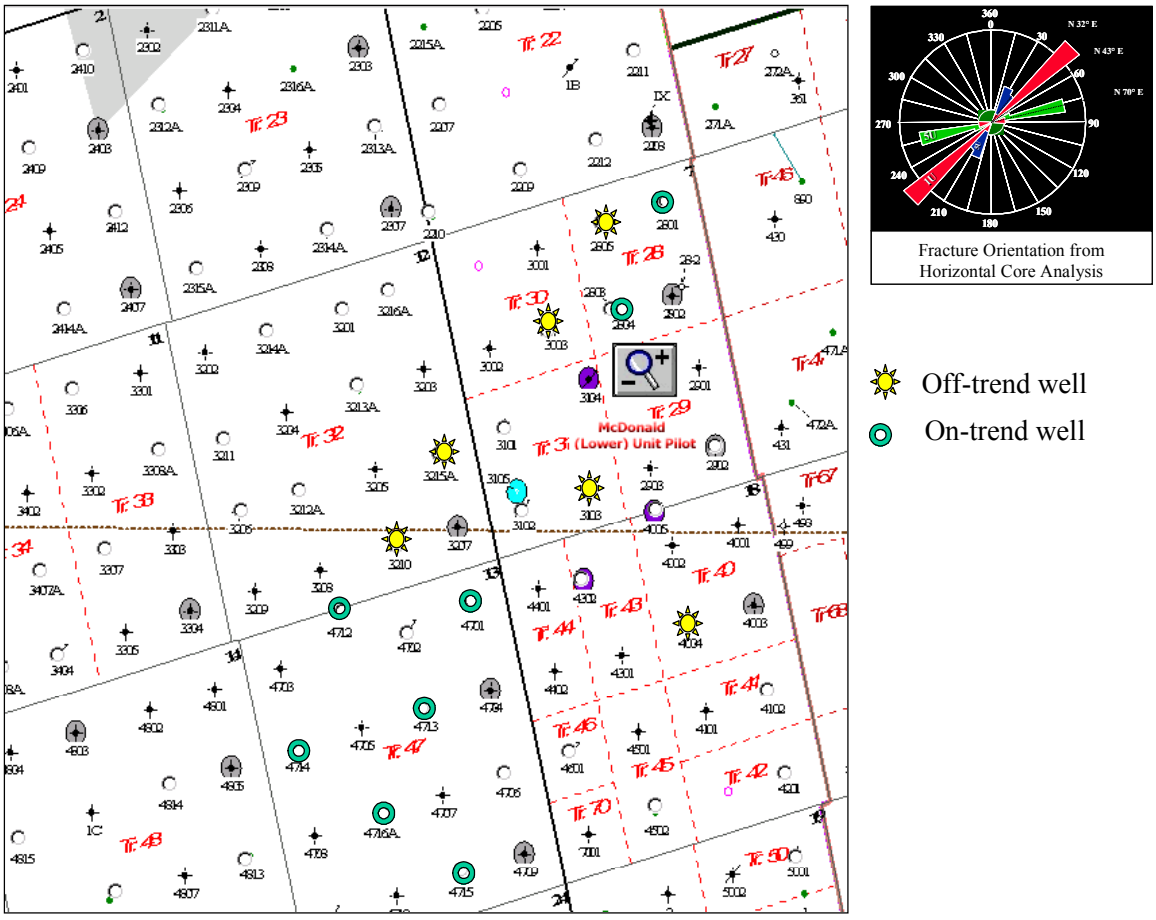

Fig. 1 - Location of On-trend and Off-trend wells in the Lower Spraberry of Midkiff Unit "McDonald" Waterflood Pilot.

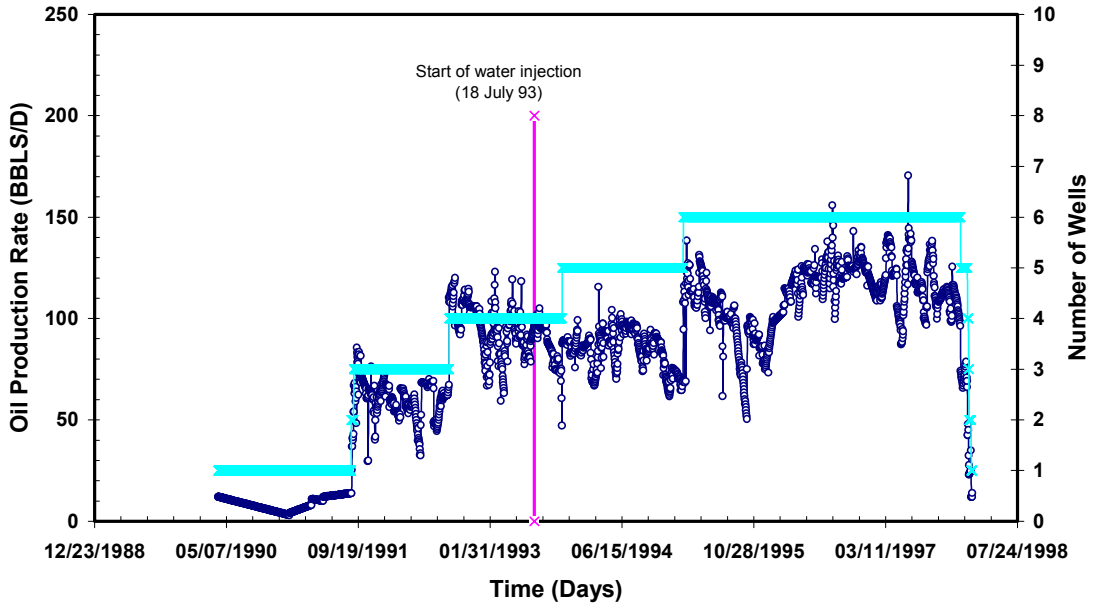

Fig. 2 - The off-trend production response of Lower Spraberry (Midkiff Unit "McDonald" Waterflood Pilot) from Wells #2805, 3003, 3210, 3215A, 4004 and 3103.

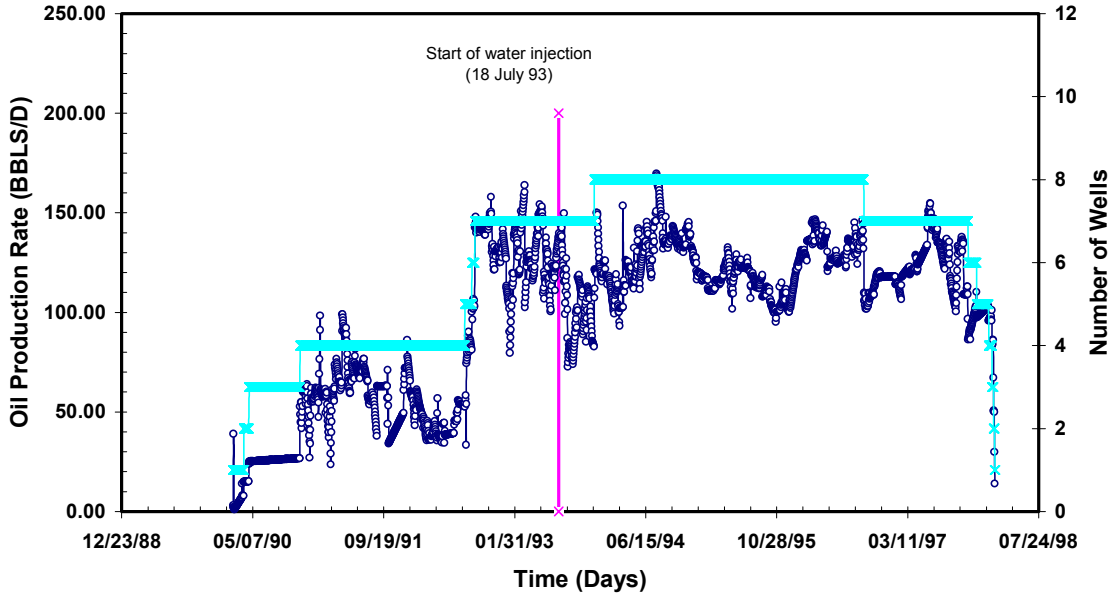

Fig. 3 - The on-trend production response of Lower Spraberry (Midkiff Unit "McDonald" Waterflood Pilot) from Wells #2801, 2804, 4701, 4702, 4712, 4714, 4715 and 4716A.

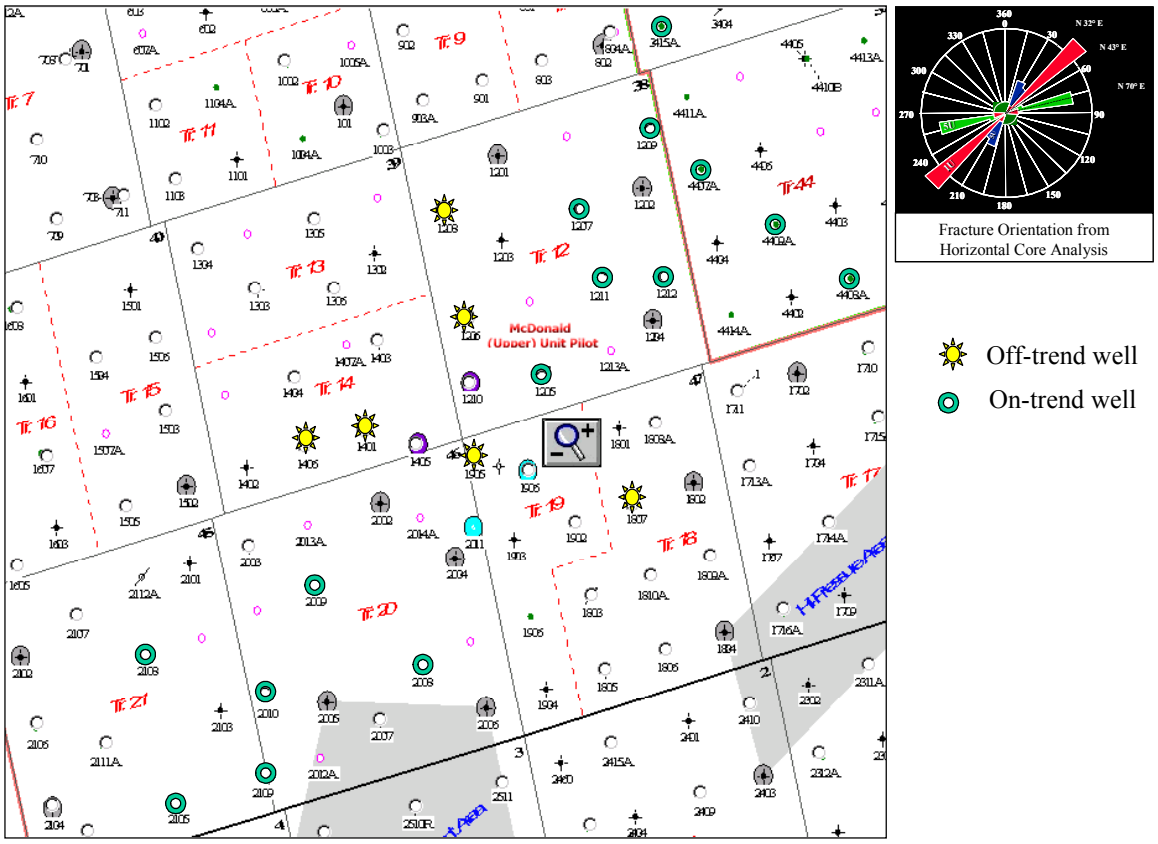

Fig. 4 - Location of On-trend and Off-trend wells in Upper Spraberry of the Midkiff Unit "McDonald" Waterflood Pilot.

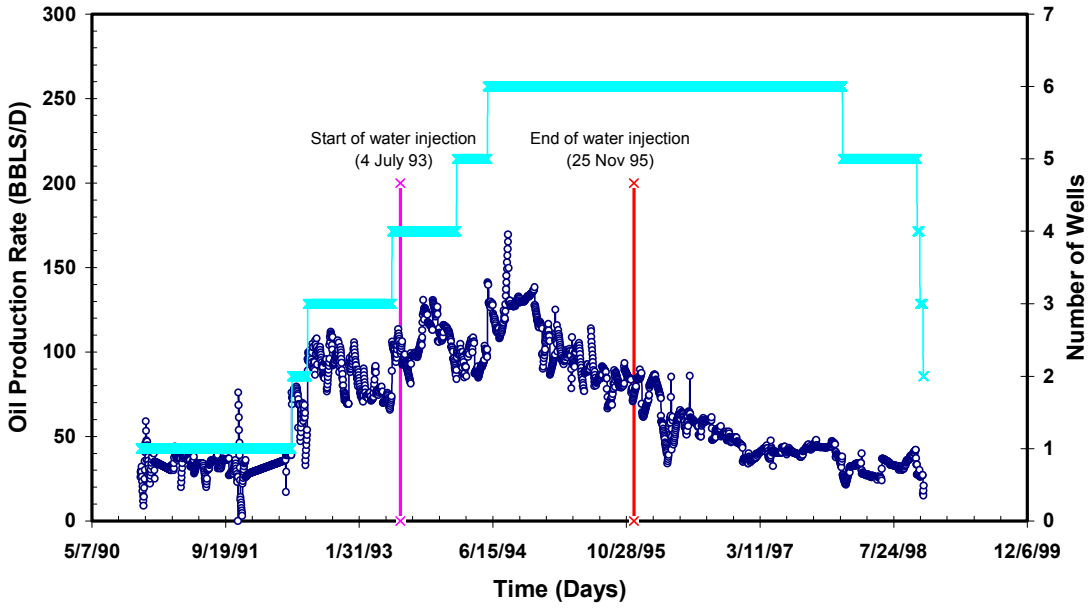

Fig. 5 - Off-trend production response of Upper Spraberry (Midkiff Unit "McDonald Waterflood Pilot") from Wells #1206, 1208, 1401, 1406, 1807 and 1905.

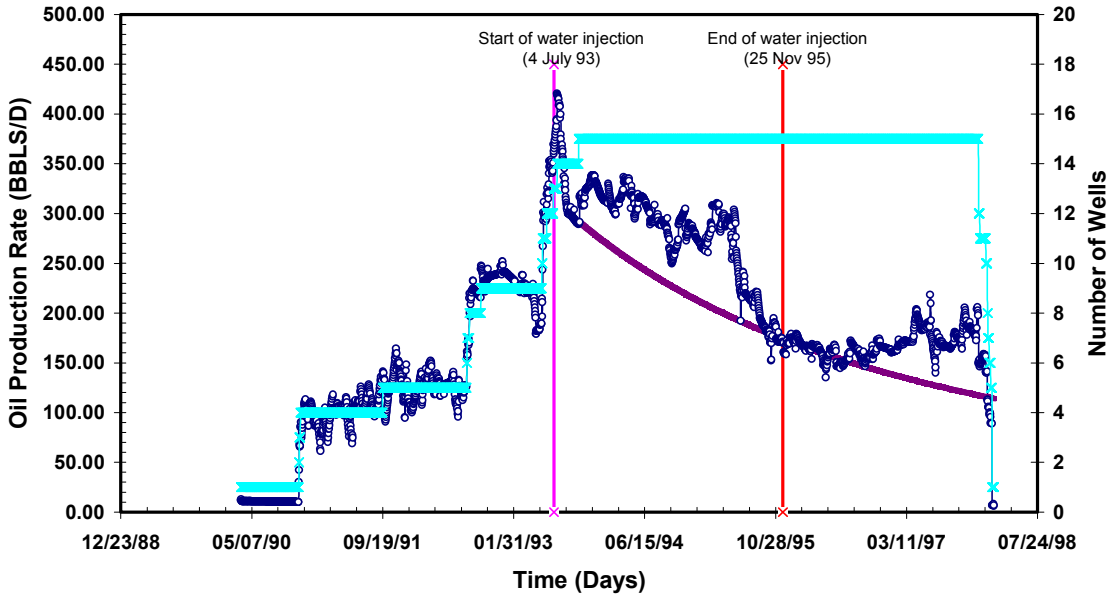

Fig. 6 - On-trend production response of Upper Spraberry (Midkiff Unit "McDonald" Waterflood Pilot) from Wells #1205, 1207, 1209, 1211, 1212, 2008, 2009, 2010, 2105, 2108, 2109, PU#3415A, PU#4407A, PU#4408A and PU#4409A.

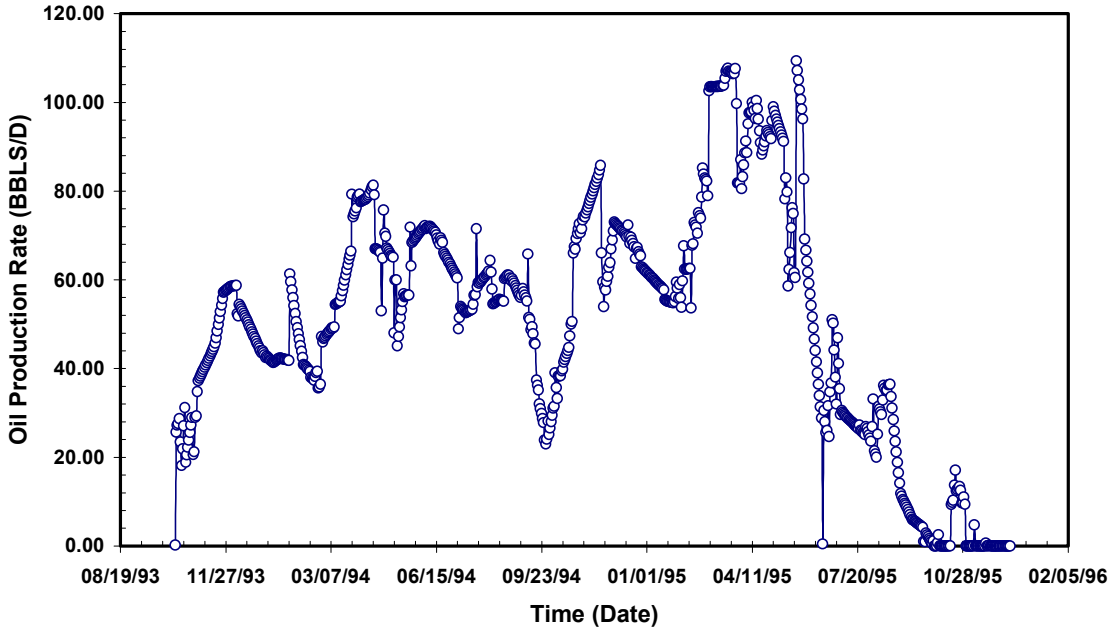

Fig. 7 – Incremental oil recovery of Upper Spraberry (Midkiff Unit "McDonald" Waterflood Pilot) from on-trend wells after waterflood baseline.

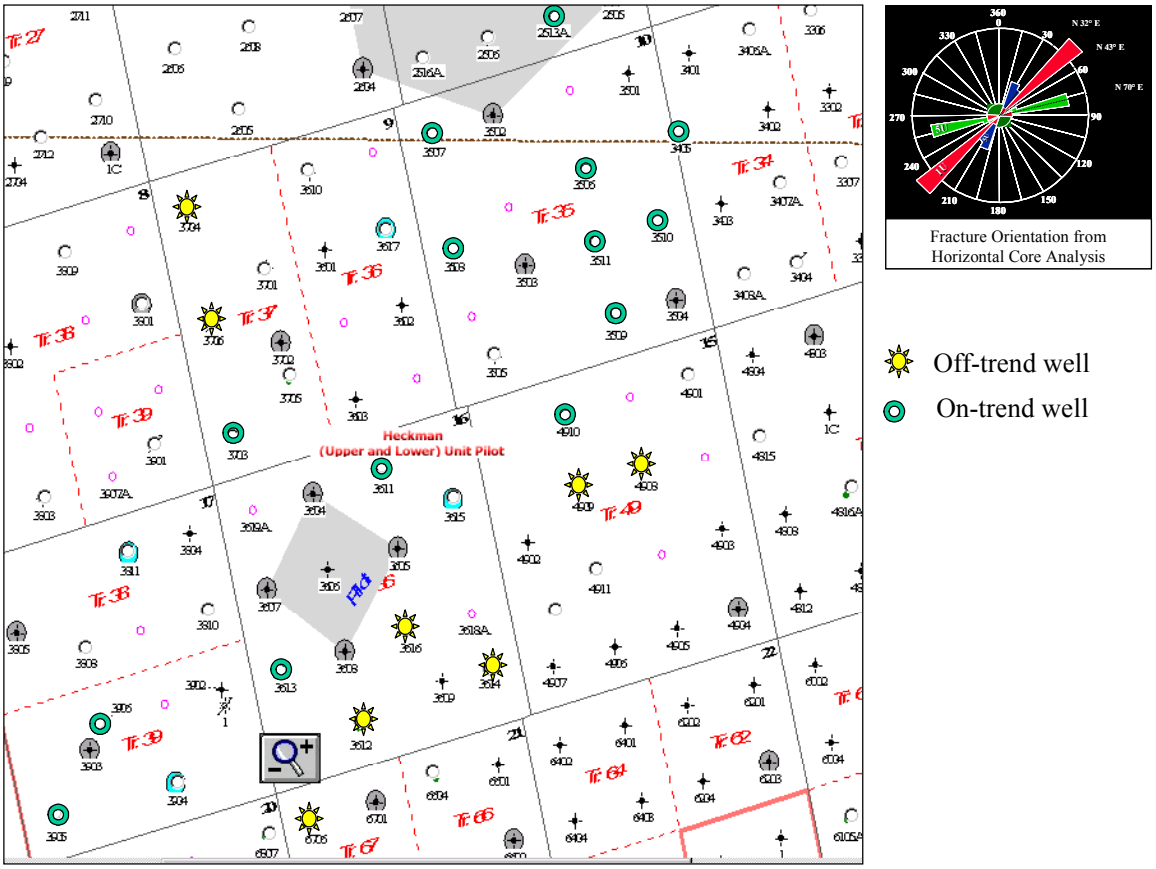

Fig. 8 - Location of On-trend and Off-trend wells in the Lower and Upper of Midkiff Unit "Heckman" Waterflood Pilot.

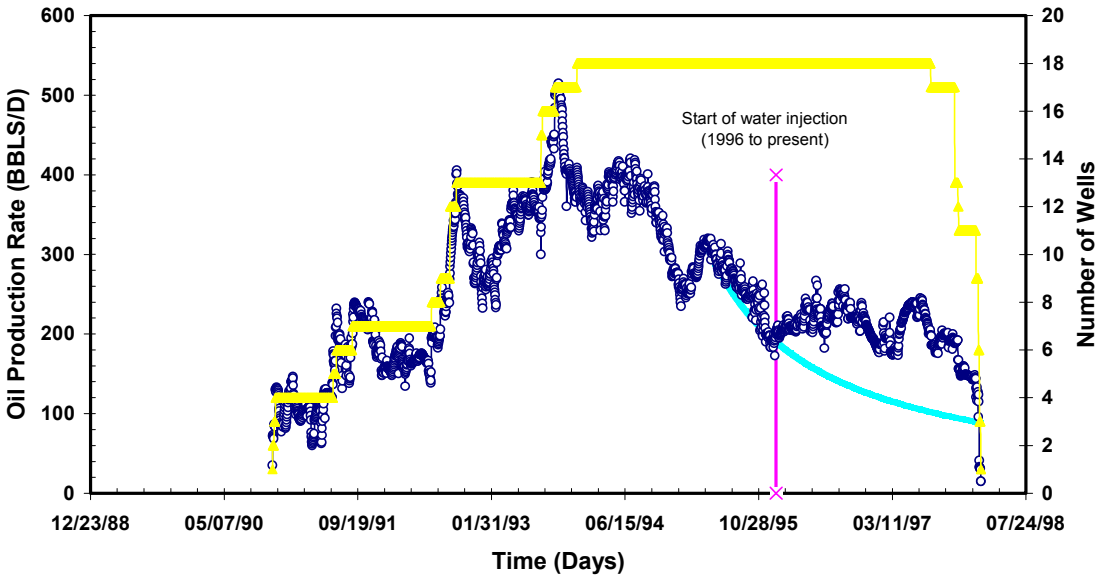

Fig. 9 – On-trend production response of Upper and Lower Spraberry (Midkiff Unit "Heckman" Waterflood Pilot) from wells #2413A, 2513A, 3405, 3506, 3507, 3508, 3509, 3510, 3511, 3611, 3613, 3703, 3705, 3808, 3810, 3905, 3906 and 4910.

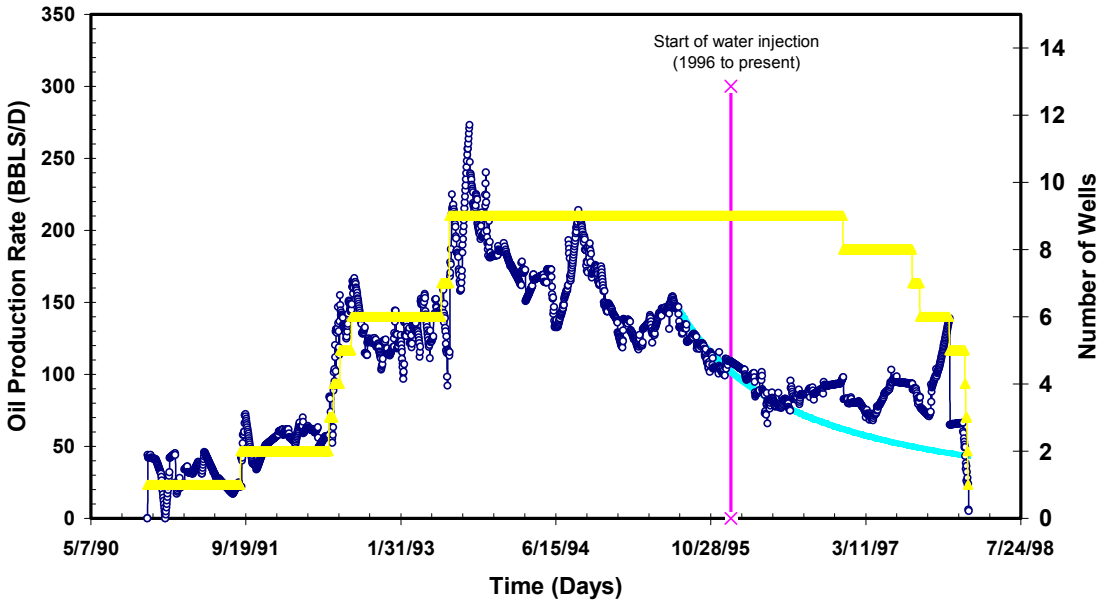

Fig. 10 – Off-trend production response of Upper and Lower Spraberry (Midkiff Unit "Heckman" Waterflood Pilot) from wells #3612, 3614, 3616, 3704, 3706, 4908, 4909, 6706 and 6807.

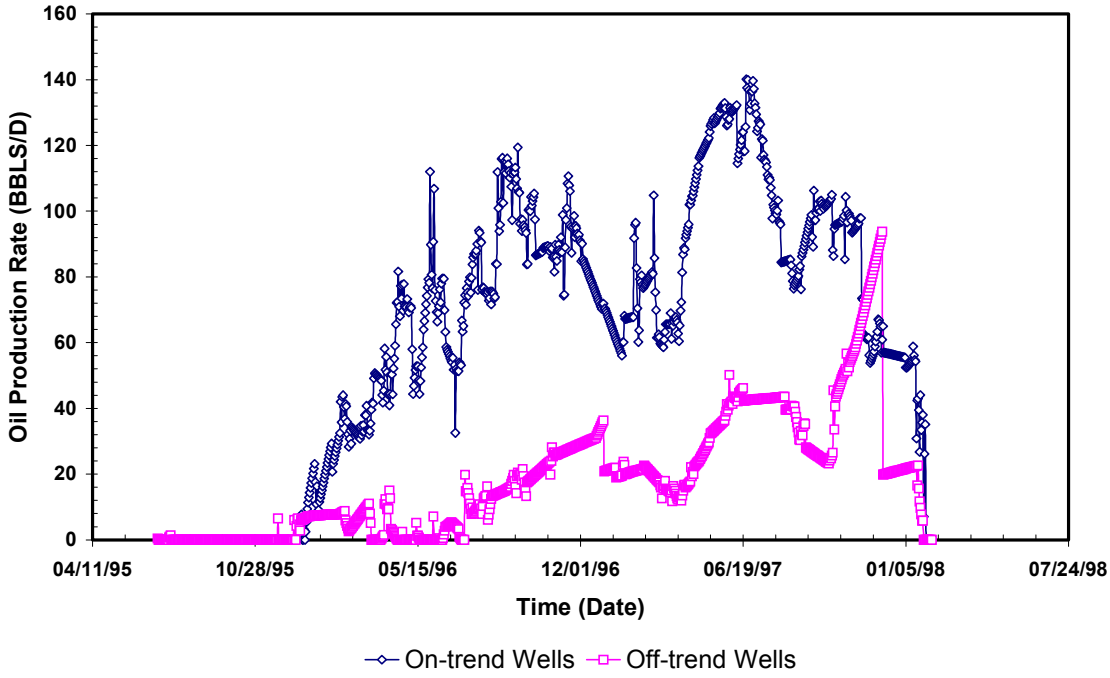

Fig. 11 – Comparison of incremental oil recovery between off-trend and on-trend wells of Upper and Lower Spraberry (Midkiff Unit "Heckman" Waterflood Pilot).

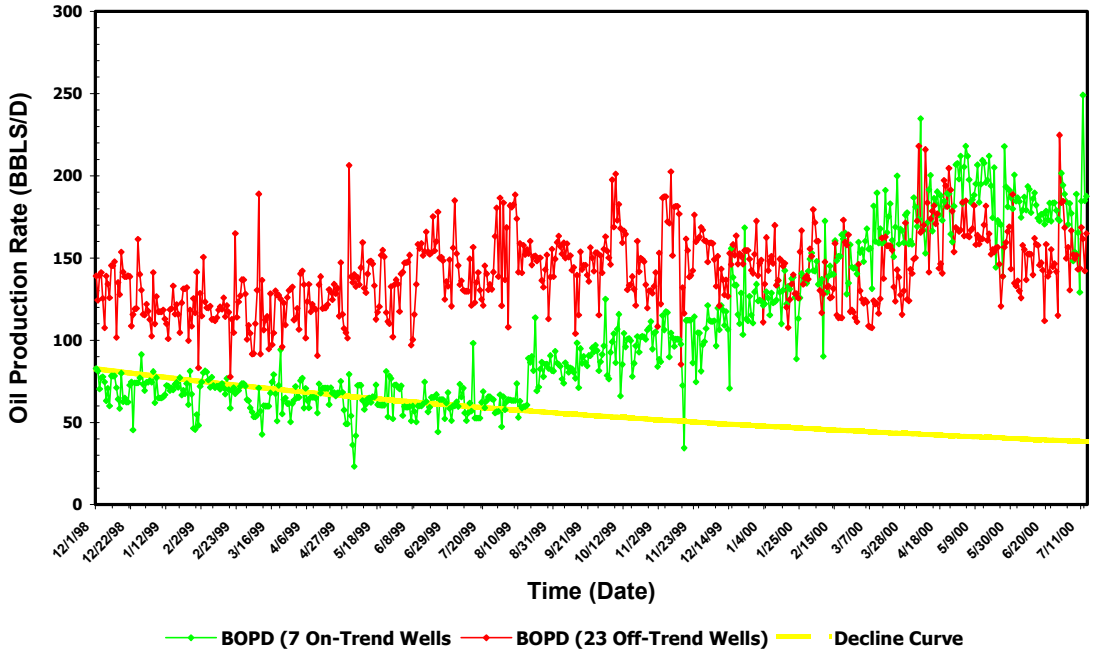

Fig. 12 – Comparison between on-trend and off-trend production rate of Upper Spraberry in the ET O'Daniel Pilot.

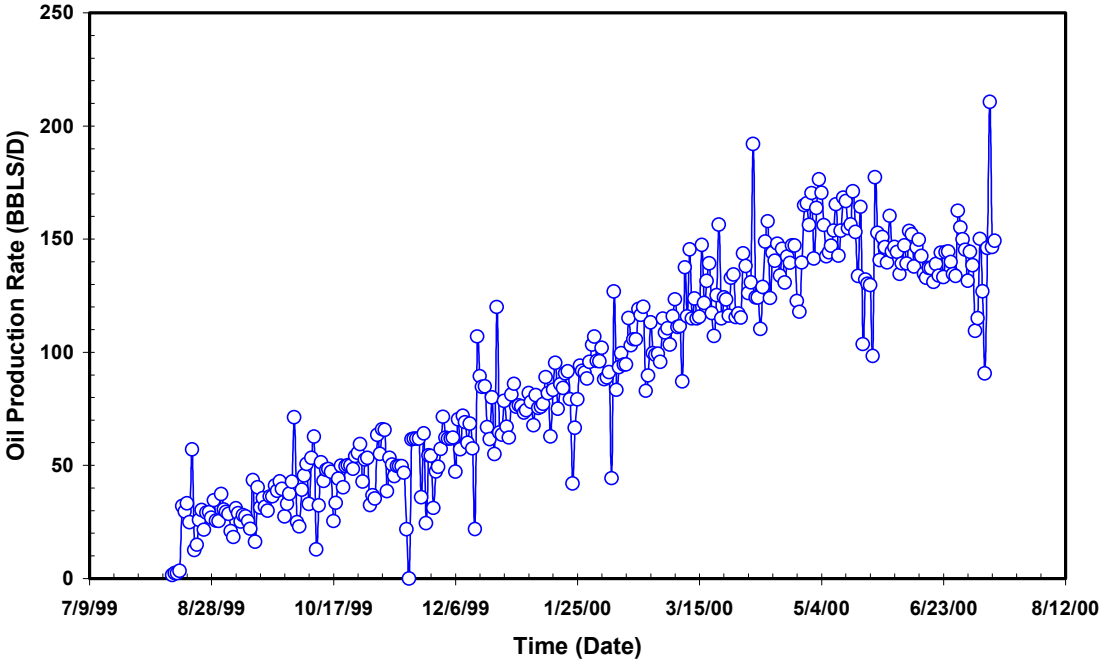

Fig. 13 – On-trend incremental oil recovery of Upper Spraberry in the ET O'Daniel Pilot.